INNOVATION TO REALITY – INTRODUCING STATE-OF-THE-ART PROTECTION AND MONITORING TO EXISTING LOW-VOLTAGE SWITCHGEAR

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Abstract – A large array of components with communications capabilities exists for constructing protection, monitoring, and control systems for power distribution equipment (switchgear). While most of these components or devices perform multiple functions, a typical application will contain at least several different devices that must be interconnected to function as a complete system. An example might be multifunction meters coupled with multifunction protective relays, and a programmable logic controller for a complete system. Could it be possible to take the functions of multiple microprocessor-based devices and combine those functions into a single-processor system? Would the new system be able to execute instructions for fast acting overcurrent protection while gathering simultaneous metering data from every circuit breaker in the equipment line-up?

In this paper, the authors discuss a unique approach to low-voltage switchgear protection and the process of transitioning this concept to a real-world application. The paper describes the architecture and functionality of this approach and explains how a centrally controlled system can provide advanced monitoring and protection functions much more effectively than existing systems.

Installation and field-testing are important steps in the process of introducing new technology. This paper will describe why retrofitting an existing switchgear lineup may be preferable to starting with new switchgear. It will also describe the considerable planning involved in the retrofit process to minimize the effect on the customer's operations.

The paper concludes with a discussion of how well the system functioned in an actual operating environment.

Index terms – retrofit, communicating devices, single-processor

I. INTRODUCTION

A. Background

Communicating devices and associated networks are increasingly common in electrical power distribution equipment. The networks provide the important connection among individual devices, such as trip units, meters, and protective relays, for gathering and reporting critical power system information. In low-voltage power systems (600 V and below), a network of communicating devices can provide supervisory control functions, gather substation electrical data, and report event status to a central control computer.

A challenge in working with communicating devices has been handling large amounts of data from multiple devices in a workable time frame. Speeds and bandwidth on commercially available networks have recently reached levels at which it is reasonable to consider gathering data from every circuit in a substation (up to 30 circuits) and use that data to perform real-time control and protection functions. Channeling all these data to one central processor located in the low-voltage substation provides an opportunity to perform protection, control, and monitoring functions that are either not possible with conventional hardware and/or software or are extremely difficult to implement in electrical distribution equipment.

B. Shortcomings Of Present-Day Communication Systems

Although modern communication networks have the speed and bandwidth to communicate with many devices, variable latency caused by communication delays, device response time, and the amount of information requested from each device has relegated communication devices to supervisory and data-gathering functions. In order to add protection, such as overcurrent tripping, to the list of functions handled by the network, a fast, reliable, and deterministic communication system is necessary.

Variables affecting system response, such as the number of communicating devices and the length of the message to and from the device, can make the system response time after an event (electrical fault) not only difficult to predict, but also slow compared to the time required by a single device to execute its own event response. Certain types of information from a device can be assigned to high-priority interrupts, but the system response is not always deterministic, nor is the performance predictable. Higher-speed networks, including Ethernet, can provide very fast communication rates, but the protocols employed do not provide the necessary predictable and deterministic response times. Protocols specifically designed for machine and device control offer promising capabilities in data rate, scalability, and reliability, but none provided the desired fast, reliable, and deterministic communication.

C. A Different Approach To Monitoring and Protection

The concept discussed in this paper uses a methodology different from that of all other electrical equipment systems to date. Communication is based on the capabilities of Ethernet, while removing the time variation introduced by collision-detection, multiple-access (CSMA/CD) protocols. Communication is structured to yield fixed latency and subcycle transmission times between a central processor and all the devices in the system. Fast communication and fixed latency are key enablers for using a communication network to perform critical control, monitoring, and protection functions.

A second distinction is in the types of information carried on the network. Rather than processed summary information captured, created, and stored by such devices as trip units, meters, or relays, the actual raw parametric or discrete electrical data and device physical status are carried on the network. The data sent from the devices to the central processor are the actual voltages, currents, and device status. As a result, any microprocessor on the network has complete system wide data with which to make decisions. It can operate any or all devices based on information derived for as many devices as the control and protection algorithms require.

The architecture discussed here is centralized, with one microprocessor responsible for all system functions. Alternate architectures, such as distributed and semi-distributed, were considered, but the central processor architecture provides the best performance. Figure 1 shows the centralized architecture applied to a typical lineup of low-voltage switchgear, with a central computer performing the control and protection functions and each breaker acting as a node on the network. The key advantage of this architecture is that the single processor has the information from all nodes simultaneously. Thus, protection and control schemes can be designed that consider the values of electrical signals, such as current magnitude and phase angle, at one or all circuit breakers in the system with equal ease. This allows the implementation of circuit-specific zone-protection functions as easily as a simple overcurrent function at a single circuit breaker.

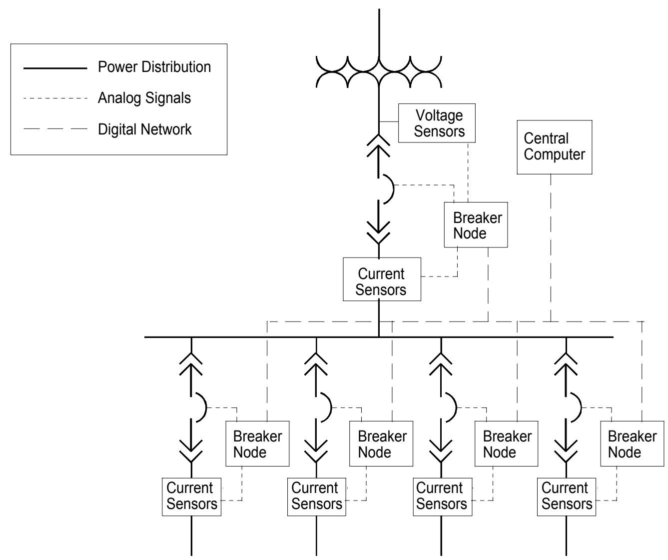

Fig. 1. Centralized architecture applied to a typical low-voltage switchgear lineup.

The following are examples of the advanced protective and monitoring functions possible with a single-processor architecture where all devices provide data simultaneously.

- *Multiple-source ground fault* -- Includes simple main-tie-main configurations with multiple neutral-to-ground bonding connections to more complex systems incorporating utility transformers, emergency generators, paralleling equipment, uninterruptible power sources, and bypass breakers.

- *Zone-selective interlocking* -- Reduces the delay time for overcurrent tripping (short time or ground fault) when the fault is between a main or tie circuit breaker and a branch feeder circuit breaker.

- *Bus differential* -- A type of bus fault protection seldom used in low voltage equipment due to the costs associated with multiple current sensors on each circuit breaker and the need for a set of sensitive (and usually costly) protective relays. Sensitive bus differential protection can significantly reduce the damage associated with arcing faults.

- *Dynamic zone protection based on system configuration* -- Provides the ability to dynamically adjust overcurrent protective settings on upstream breakers based on the settings of a downstream breaker sensing a fault. Back-up protection provided by the main or tie circuit breaker can be much tighter to the feeder breaker that is sensing and attempting to clear the fault. Traditionally, main and tie circuit breakers are set with higher overcurrent pick-up and delay settings to be selective with the largest feeder circuit breaker on a bus. Closely set back-up overcurrent protection for smaller feeders is sacrificed when the mains and ties are set to be selective with larger feeders. Dynamic zone protection could provide the closest overcurrent back-up protection for all feeders on a bus, independent of the differences in trip settings between main and feeder breakers.

- *Simultaneous event reporting on all devices* -- The system could be capable of recording any change in status of any circuit breaker or system component and could generate an alarm and / or send an electronic notification detailing the event. An event triggered by a fault could generate a simultaneous capture of all voltages and currents on all circuit breakers within the switchgear line-up. This synchronized collection of data on all circuit breakers during an event can provide the critical information needed for determining the cause of the circuit breaker trip and getting the majority of the system back on line quickly.

II. FROM CONCEPT TO REAL-WORLD APPLICATION

This technology represents a significant departure from traditional systems. As with any technology that is significantly different from traditional systems, field experience is essential. Testing in a laboratory is a necessary first step but does not cover three significant areas.

1) *Laboratory Testing Covers only Known Usage Cases*: For this system, a database management tool linked the test cases to the product requirements. Test procedures were based on the product specifications and detailed requirements for the systems. Test results and pass/fail criteria were linked back to the specifics of the product requirements. The engineers also expanded the test cases by performing failure mode effects analysis (FMEA) to add unexpected cases, providing more than simple coverage. Although testing is thorough, the unexpected field situation can still be missed.

2) *The Environment Is Different:* In particular the electromagnetic (EM) field caused by motor loads, transformer inrush, and switching transients is different in the field. Laboratory testing to ANSI C90.1 is performed prior to beta testing to cover high-frequency, high electric field situations. Other laboratory testing for the influence of high-strength, low-frequency magnetic fields is also performed specifically because such fields are present in switchgear.

3) *Customer Interface*: Unlike previous, and some current, switchgear designs in which the devices are black boxes with minimal user interface, this new concept includes a touch screen human-machine interface (HMI). The HMI provides full system data, including electrical parameters (current, voltage, and power), status (breakers closed or open), and events (breakers tripped, alarm set points exceeded); serves as the input device for all of the system settings; and allows complete operation of the switchgear.

To perform this full range of features, the HMI requires multiple screens, menus, and options. The HMI designers, based on feedback from a customer focus group, initially lay out the screens. But the best test of the information presented and the navigation through the screens comes from day-to-day operation by individuals who are not intimate with the design of the product. The HMI should have a familiar “feel” and operation, like other available touch screen or input and monitoring devices. A primary is to make the HMI as intuitive as possible in its operation.

A. Why a Retrofit?

The primary reason for choosing an existing installation for the beta site was to introduce this new concept in an operation that was already electrically stable. With new installations, unanticipated issues frequently arise while the system is being commissioned. Often the issues are related to the primary power, not the control and monitoring system, and can be very time consuming to resolve. The goal of the beta site is to evaluate the operation of the new system in a real-world environment. The stable electrical operation of an existing system simplified the root-cause analysis of field-identified issues, as well as the subsequent testing of potential resolutions.

The retrofit was performed on a low-voltage switchgear installation that already had some power-monitoring capability. This monitoring system was left in place when the gear was retrofitted with the new system hardware. The existing monitoring system provided an independent source of data to which new system data could be compared.

The choice of a retrofit installation versus a new installation also provided a much higher probability that the system installation and commissioning dates would be maintained. In a new installation, starting the beta equipment is dependent on energizing the switchgear. Energizing new switchgear is dependent upon the construction schedule of the new facility. Any delay in construction, including uncontrollable factors like weather, delays the start of the beta testing. In extreme cases, construction delays can extend for months. The retrofit of this beta site was scheduled during the equipment shutdown for the upgrade of the substation transformer. The actual date of the retrofit was within 2 weeks of the original schedule developed several months earlier.

B. The Shadow System

The beta site installation had to provide critical information about the function of the system in an actual electrical environment by monitoring and reporting the power system's electrical data. Since the system provides both monitoring and protection, it is designed to react to overcurrents and other electrical fault conditions. It was critical that the system operation be tracked to verify its response to electrical conditions in the substation, but equally critical that the system not cause any shutdown of the breakers in the switchgear.

This was accomplished with remote access to the system events log. Comparing the reports from the events log with the on-site power management system and weekly feedback from the site allowed tracking and verification of unexpected situations without disrupting plant operations.

C. Secondary Objective Of The Retrofit

The beta retrofit also provided an opportunity to evaluate the feasibility of this new product as a retrofit into existing switchgear. Typically, retrofitting switchgear with new hardware is a difficult and time-consuming process.

Some issues that could be encountered when retrofitting existing switchgear with traditional devices (intelligent and nonintelligent) include the following:

- The retrofit usually requires that the breakers be upgraded with new electronic trips. If this includes current transformer or current sensor replacement, some bus bar disassembly and reassembly may be required.

- Adding new features to the equipment may mean adding new intelligent electronic devices (IEDs). Disassembly of the switchgear may be required to mount new IEDs.

- Wiring – Each added IED must be wired to its associated circuit breaker and sensor(s) and interconnected to other IEDs within the switchgear.

  - Wiring is probably the most difficult task, since exact mounting locations may not be known. Also, interconnections between IEDs may require point-to-point wiring rather than a multi-wire harness.

  - Different functions require different interconnects, uniquely designed and built on site.

Summary of the new system retrofit:

- Circuit breaker upgrades were simple, with the addition of a shunt trip and auxiliary switch to each breaker.
- There was a standard set of hardware to install. The central processor handles all protection, monitoring, and control functions. Current and voltage signals have standard designs and locations within the switchgear. The IED for the circuit breaker mounts in a standard location above each circuit breaker cubicle.

- Wiring was standard at the breaker and throughout the switchgear. Interconnect points and device locations were known. This made it possible to prefabricate the majority of mountings and harnesses. The interface to the circuit breaker was also well defined

III. <u>DETAILS OF THE NEW SYSTEM RETROFIT</u>

Once a potential beta site was identified, the beta team obtained a copy of the electronic drawing files to evaluate the suitability of the switchgear. One of the primary factors in determining the site's suitability was confirming that the new system had the functionality required by the existing equipment. When it was determined that the functionality matched, the remainder of the beta issues were resolved and a customer agreement was reached.

The beta site identified and agreed upon was the Lafarge North America plant in Whitehall, PA. A 500kVA unit substation had been designed and manufactured in late 2001 and was installed in early 2002, as shown in Figure 2. The substation is used to feed 480 volt loads for the quarry limestone crushing systems, raw material receiving, and the associated transport systems to storage silos. The 480 volt distribution equipment consists of five-800 amp frame feeder circuit breakers and provisions for one future 800 amp frame circuit breaker, as shown in Figure 3.

Figure 2. 500kVA Unit Substation

Figure 3. Low Voltage Switchgear Units

A. Designed Upfront

Detailed manufacturing documentation provided by the switchgear factory allowed the beta team to design the new system in the engineering office before visiting the site. This was a key step in the successful installation process. The detailed engineering design included a complete bill of material for the new system (all hardware items, including terminal blocks, brackets, fasteners, terminals, and the major system components), detailed schematics of the breaker element and the switchgear, and detailed mechanical layouts of system component locations.

During the design process, the decision was made to locate the major system components—the central processors, UPS, and communication switches—in a separate switchgear section. This decision was initially made because auxiliary equipment originally designed into the switchgear occupied the space where the new components would typically be located. As the project progressed, the decision to locate these components outside the switchgear enclosure became an obvious benefit.

As part of the beta test process, the new equipment was monitored and upgraded as new releases with advanced features were introduced. Having some of the system components in a separate section allowed easier access without the concern of exposing or disturbing any 480V equipment. This separate section has only 120V control power supplied by the switchgear control power transformer.

B. Structured Design

The new system uses a structured hardware design, regardless of the switchgear size or functionality. This fact enabled the gear to be quickly and completely designed from the factory drawings without visiting the site. There are six primary design aspects of the new system: breaker compartment elements, communications network, central computers, control power, voltage transformers (VT), and HMI.

The breaker compartment elements consist of the phase current transformers (CT), the node electronics (node), and the interconnection wiring to the circuit breaker. The CTs are designed as three-phase units in single molded enclosures that mount to the breaker compartment rear barrier. Each three-phase CT includes open-circuit protection and the harness for connection to the node. For four-wire applications, a current sensor is added to the neutral to provide the fourth current input to the central computer.

The node is the interface between the circuit breaker and the central computer and also provides the analog-to-digital conversion of the current and voltage signals for the central computer. The node has standard multi-pin connectors for the current, voltage, control power, and communication wire harnesses. A terminal block was added to the breaker compartment for connecting the control power distribution in the switchgear to the node harness. The breaker cubicle already had terminal block points dedicated for breaker accessories, such as the auxiliary switch and the shunt trip. An interconnect harness was designed to connect the breaker terminal block to the node. Because all breaker compartment wiring is standard, the harness designed for one breaker could be duplicated for each of the breakers in the switchgear.

The communications network uses two commercial, off-the-shelf, Ethernet network switches. Each node has two communication ports, one for each network switch. Dual communication networks were used to eliminate single points of failure. A network cable connects each switch to its respective central computer.

Redundant Single-processor Industrial Computers

The central computer compartment houses the two central computers, as shown in Figure 4, and requires only control power connections and the network connection from the network switches. Because this site used an auxiliary section for the computer compartment, the network switches were located in the switchgear near the nodes. Only two network cables are required to connect the switches to the central computers in the auxiliary section. The central computer compartment was outfitted with additional communication equipment to provide remote access to the system, so the design team could monitor it without traveling to the site.

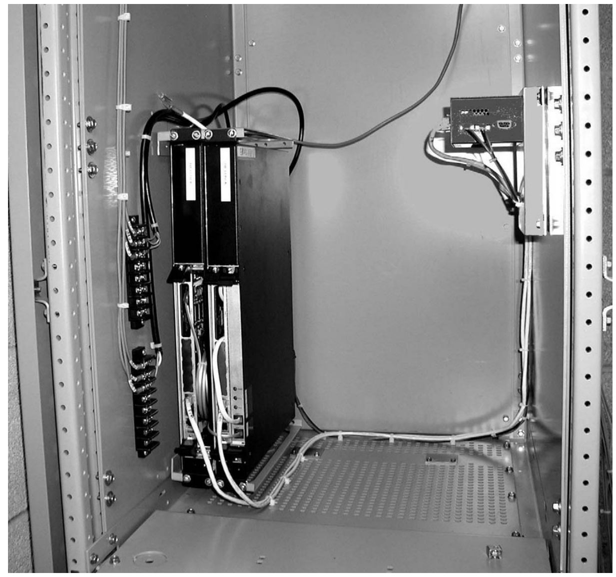

Figure 4. Redundant Single-Processor Industrial Computers

Control power consists of two independent 120V AC sources feeding control power transfer relays, which in turn provide input power to two uninterruptible power supplies (UPS) as shown in Figure 5. The outputs from the UPSs provide two independent power distribution circuits to the central computer compartment and each breaker compartment. All terminal points associated with control power distribution are dedicated and consistent throughout the switchgear, including the breaker compartments and the computer compartment, simplifying the wiring design. Although the standard design is based on two independent control power sources, the beta site switchgear had only a single control power transformer. The two inputs to the control power transfer relays were taken from individual windings on the secondary of the switchgear-mounted control power transformer. In a new-equipment application or in a full retrofit application, the standard design with two independent control power sources would be used.

Figure 5. Redundant Uninterruptible Power Supplies

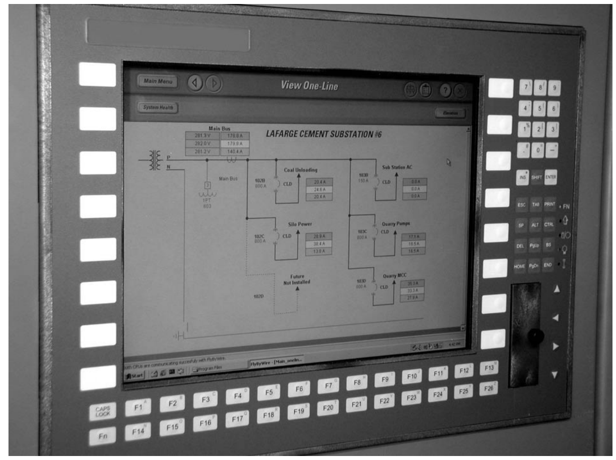

Figure 6. Human-Machine Interface (HMI) With Touch Screen

Voltage transformers convert bus voltages to a level usable by the system. The beta site power transformer has a 480 V wye secondary. A three-phase, wye-wye voltage transformer provided the required 18 V signal to the node. The system presents less than 1 VA of additional burden, so the VTs were connected to the load side of the same fuses used for the existing metering voltage transformers. Since there was only one 480 V source for the beta site switchgear, only one voltage input was needed for the entire system. The secondary of the VT was connected directly to a main node in the switchgear–transformer transition section.

The HMI mounts in an instrument compartment within the switchgear lineup or in a nearby auxiliary section, as shown in Figure 6. The HMI is connected to the system via a communication cable and requires control power from the control power distribution in the switchgear. The touch screen on the HMI provides variable access to substation electrical data, status and event information for the substation, and control of the circuit breakers.

C. Prefabricated Hardware For The Retrofit

Two prototype switchgear sections, of the same type as used on the switchgear shipped to the beta site, were acquired for the engineering test lab. The prototype gear was used to verify the mechanical fit of all the components and to define wiring harness lengths.

1) *Mechanical Parts:* All of the necessary brackets, wire tie-down points, terminal blocks, and current transformers designed for the gear were assembled into the prototype gear to insure proper fit. The majority of the mechanical mountings used existing hardware and pilot holes in the gear. This dramatically reduced installation time by eliminating field-drilling of barriers and panels. Installation of most of the components simply required removal of some hardware and then reinstallation with the system components.

2) *Wire Harnesses:* The prototype switchgear was used to generate detailed configurations of the wire harnesses to be used in the switchgear. Due to the common design of the control power distribution, a small number of unique harnesses were required for the entire beta site installation. With the detailed definition of the wire lengths and terminations, the factory manufactured the complete harnesses.

The harnesses connecting the node to the CTs, control power, and the circuit breakers were also prefabricated with the multipin node connectors on one end and the correct terminal type and wire marker on the other end.

3) *Auxiliary Section:* Mounting the control power transfer relays, UPSs, and central computers in an auxiliary section allowed that section to be assembled and completely wired in the factory. It was then shipped to the site and installed. One problem was that the exact location of the auxiliary section was unknown, so the harnesses could not be fabricated complete. The switchgear ends of the harnesses were finished, but the auxiliary section end was unterminated, with wire markers only. The wires were cut and terminated in the auxiliary section before control power was connected.

D. Procedures

With the design completed upfront, the statement of work for the actual retrofit activities could now be developed. All the components to be installed and all the wiring to be added or modified was now known. Having the prototype gear in the engineering lab provided the opportunity to define the tasks for the individuals who would be working on the retrofit. While the structured design of the system allowed the outline of the work to be developed, the prototype switchgear sections allowed detailed installation procedures to be defined. The procedures were an invaluable part of the retrofit process, particularly with the limited time available during the shutdown. The procedures also helped identify dependent and independent tasks and the order in which they had to be performed. Reviewing the detailed procedures helped insure that no tasks were omitted.

E. Planning – Prework, Shutdown Critical, Postshutdown

Once the detailed bills of material and procedures were completed, the work was broken down into prework, shutdown, and post-shutdown activities.

1) *Prework:* This was coordinated with the customer around their normal maintenance schedule and the switchgear shutdown to replace the power transformer. The facility normally shuts down a section of the plant on Wednesdays. During these weekly maintenance shutdowns, individual breakers were removed from the switchgear for installation of shunt trips and auxiliary switches before the major equipment shutdown. The auxiliary section and the wireway connecting it to the switchgear were also installed in the substation room before the shutdown.

2) *Shutdown:* The critical tasks to be performed during the primary shutdown included installation of the three-phase CTs, nodes, and associated wiring in each breaker compartment; installation of the voltage transformers and communication network switches; and installation of the interconnecting wiring between the switchgear and the auxiliary section. All of theses tasks were performed on or near the 480 V bus and only when the switchgear was shut down.

3) *Pos-tshutdown*: Tasks that were completed after the switchgear was reenergized included termination of the interconnecting wiring in the auxiliary section and installation of the HMI in the switchgear instrument compartment door. The last task was the startup and commissioning of the system. Having the bulk of the system hardware components in an auxiliary section proved to be a major benefit and is recommended for any retrofit application. Although the system is designed to reside entirely in the switchgear, the auxiliary section reduces the shutdown work scope and provides an opportunity to monitor and operate the switchgear from a safe distance.

F. Experienced, Trained Retrofit Team

The retrofit team consisted of two field service engineers and two factory engineers. All four have multiple years of switchgear experience; one had previous experience at the site and two were trained in the system hardware installation using the engineering lab prototype switchgear. This proved invaluable during the retrofit. Knowing the components, interconnections, harnesses and terminal points and the order in which the tasks had to be performed meant that the work progressed continuously and orderly throughout the shutdown. The structured system design insures that the majority of the components and connections are the same, regardless of the gear specifics. Once trained on installing the system in a switchgear lineup, the engineer finds the process similar, with a few minor exceptions, for any lineup of the same type of equipment.

G. The Retrofit Process

1) *Pre-shutdown:* Before the major shutdown, the shunt trip and auxiliary switch kits, with the installation procedures, were shipped to the site. All of the breaker updates were performed over the course of several Wednesday shutdowns.

All of the components, harnesses, and hardware were packaged into working groups and shipped to the site. The complete bills of material facilitated getting all the necessary parts on site before the shutdown. A missing component, large or small, can be catastrophic during the limited time of a shutdown. Special tools needed for the installation or for repairing any damaged parts, such as a connector, were also on site.

2) *Shutdown:* The installation was scheduled to coincide with a transformer upgrade. The outage was scheduled for 14 hours and the plant was scheduled to resume production later in the day. The switchgear feeds raw materials to production and coal to the kilns, so is critical to getting the entire plant back in operation. The retrofit had to be completed in the scheduled time.

The engineering installation team arrived at the site the afternoon prior to the shutdown. The status of the prework was reviewed, the parts were inventoried, and work responsibilities were assigned from the procedures. Work also started on the auxiliary section.

The shutdown work was divided into four tasks: pull and install wiring in the switchgear; install CTs in the transformer transition section; install voltage transformers; and install CT's, nodes, and wiring in the breaker compartments. Two of the engineers worked in the breaker compartments and two engineers worked on the other items. Segregating the work tasks to separate areas of the switchgear allowed several engineers to work in parallel.

While the initial routing of the wiring in the rear and top of the switchgear was ongoing, the CTs, nodes, and terminal blocks were installed in the breaker compartments. The wiring from the top of the switchgear was then routed to the breaker compartments and terminated, completing the breaker compartment upgrades. Using this parallel, separate section approach maximized the number of people that could work on the gear and minimized the overall time required to complete the tasks. Additionally, work that had to be completed with the power off, primarily in the breaker compartments, remained the focus of the shutdown. For example, the control power wiring was terminated and installed at the switchgear end, while the other end of the wiring at the auxiliary section was not completed. None of the wiring to the auxiliary section was energized, so it could be terminated later. The work division and focusing on the tasks to be completed with the gear shutdown enabled the retrofit team to complete the switchgear work, reassemble the gear, reinstall the breakers, and have the gear prepared to be reenergized in one 14-hour shutdown.

IV. EVALUATION OF RETROFIT VERSUS EQUIPMENT REPLACEMENT

A protection system retrofit can have several distinct advantages over a complete equipment replacement if certain basic electrical requirements are still met with the existing switchgear. In this particular case, the existing switchgear was in excellent working order and was not under-rated in its short circuit or continuous current ratings. The realized advantages of the retrofit versus a complete equipment replacement are as follows:

1) *Shorter Shutdown Time:* The work to install the retrofit components and get the equipment back on line was accomplished in less than the allotted 14-hour outage.

2) *Fewer Trades Involved:* The work was focused on the secondary wiring and mounting components. The only work involving primary circuits was the installation of current sensors in the breaker cubicles and potential transformers. There were no modifications to primary cables or movement of the structure therefore there was no need for riggers or cable installers.

3) *Scheduling:* The shorter outage and fewer labor resources required for the retrofit were easier to plan and schedule since both were less than that required for a full equipment replacement.

4) *Subassemblies:* Wire harnesses and panels with system components were subassembled prior to the equipment shutdown. Most of the subassemblies only required mounting and interconnection wiring during the outage.

5) *Lower Cost:* The retrofit components supplied were a subset of the total material that would have been required for a complete equipment replacement. The retrofit utilized the minimum amount of material and labor to extend the usefulness and functionality of the switchgear and provided the user with many enhanced power system monitoring and diagnostic features for the end user.

6) *Future Flexibility:* The retrofit protection and monitoring system is software based. Once the basic system components are installed, future additions or enhancements to monitoring, control, or protection require only a software change. All hardware remains the same.

V. SYSTEM FUNCTION IN AN ACTUAL OPERATING ENVIRONMENT

The system Design Team monitored the "shadow system" remotely so that any changes in the status of the low voltage breakers or the system components would be recognized via the "system event log". Some of the breaker nodes were given settings below the actual circuit breaker protective settings so that changes in the circuit loading would create "events" such as an overload trip. Although the actual feeder circuit breakers did not trip, the nodes with the lower current settings was functioning properly by issuing a trip command to a breaker simulator and generating an event listing the current levels that caused the overload trip.

After 5 months in operation, one of the central processors went through a re-boot cycle, which generated an entry in the event log. The system designers were expecting the re-boot due to the software version that the system was running. No other action was taken by the system because the second central processor, which is part of the standard system design, remained on line and continued to provide protection and monitoring for the switchgear.

The utility experienced an outage that was also captured in the event logs. Since the system operates with redundant control power sources and UPS back-up, it was able to record the loss of power to the substation and continue monitoring the status of the breakers and the system components during the outage. Had any of the circuit breakers changed state during the outage, this would have also been recorded in the event log.

At the Whitehall plant, this system is dedicated to one 750KVA substation. The real-time data on the "One-Line Diagram" screen illustrated in Figure 7, provides a handy, quick-look snapshot of the status and health of the unit substation. The one-line diagram view is easy for plant personnel to quickly understand since the displayed data is clearly specific and universally recognizable. Graphic changes showing breaker status such as closed, opened, and tripped immediately attract an operator's attention when coming into the room. It is not necessary to physically inspect the gear by walking around and looking at each breaker to determine if everything is normal.

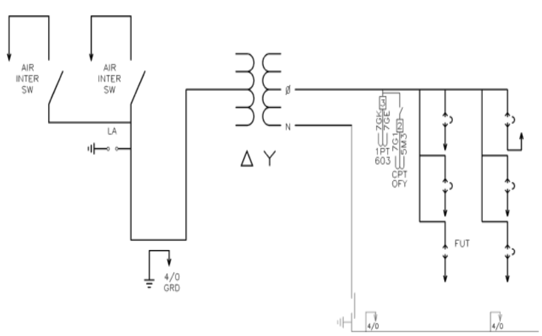

Figure 7. Unit Substation One-Line Diagram

Dynamic data, such as ampere load for each breaker, help to determine whether individual plant areas are operating normally. Line voltage, total KVA, total amps, and power factor are critical indicators of overall running conditions.

When an 'event' did occur, it was convenient to quickly switch to an easy-to-identify 'Event Screen' and read a bit of text with a time-stamp to see what happened and when it happened.

VI. CONCLUSIONS

Benefits For The End User:

The features and functionality of a monitoring system applied to a plant's power distribution system is becoming more important . Company budgets allow for fewer people on staff who have traditional "sensing and interpreting" skills tuned to a plant's power pulse. Those responsibilities are being shifted to less-experienced people. Yet power is becoming a more expensive commodity capable of having significant influence on a plant's bottom line. Decisions about power will become a very weighty issue in determining a future, or lack of a future, for process plants.

Power system monitoring, via graphical interface or touch screens, provides a clearer understanding of data that previously required interpretation to those individuals responsible for financial decisions. In corporations today, more people are responsible for making financial decisions that can have a significant business impact. Quick and easy access to power system data is one way to help insure that decisions are made with the best data available.

Benefits For The Equipment Supplier:

Retrofitting existing switchgear with state-of-the-art protection and monitoring equipment is an excellent method of gaining real-world operating experience for a new product. The process provided valuable input to the product design team on items such as:

- Defining the information to be displayed on user screens
- Monitoring component health
- Making the installation process more user-friendly
- Exploring a real-world operating environment with varying load requirements and utility power stability
- Determining user documentation requirements

Execution of protection, monitoring, and control functions from a single, centrally located processor provides a cost-effective alternative to multiple meters, protective relays, and PLC's. The modularity of the system components facilitates retrofiting into existing switchgear. The single processor concept for new or existing low-voltage switchgear provides a powerful protection, data-gathering, monitoring, and diagnostic system capable of staying in step with the needs of the power system and the user.

VII. REFERENCES

[1] Marcelo Valdes, Tom Papallo, Indrajit Purkayastha, The Single-Processor Concept For Protection And Control Of Circuit Breakers In Low-Voltage Switchgear, IEEE PCIC-2003-28